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Journal Review: Potential of Orange Peel, Fruit, and Vegetable Waste as an Environmentally Friendly Electrolyte Source for Bio-Batteries

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Abstract

The ever-increasing demand for electrical energy demands alternative, environmentally friendly, and sustainable energy sources. Conventional batteries generally rely on synthetic chemicals that have the potential to pollute the environment. One solution that is beginning to be developed is the use of organic waste as an electrolyte source in bio-batteries. This review article discusses the potential of orange peel, fruit, and vegetable waste as a natural electrolyte containing organic acid compounds, particularly citric acid ($C_6H_8O_7$), as well as mineral acids that can decompose into ions in solution, thus conducting electricity. Various research results show that the acid and water content of organic waste can produce a potential difference when paired with dissimilar metal electrodes, thus generating an electric current. In addition, the pH characteristics and natural electrolyte content of the waste indicate its suitability as a substitute for hazardous chemicals in batteries. Thus, the use of orange peel, fruit, and vegetable waste has the potential to become an environmentally friendly bio-battery innovation that can support efforts to reduce dependence on conventional batteries while contributing to sustainable organic waste management.

Introduction

Electricity plays a crucial role in everyday life, making it inseparable from human activity (Indainanto et al., 2023; Hansen & Schulze, 2025; Dahiya et al., 2024). This demonstrates that nearly every aspect of human life requires electricity. From daily routines to industrial needs, everything depends on electricity (Al Mubarak et al., 2024; Apeh & Nwulu, 2024; Qasem & Abdulrahman, 2024).

Energy is generated from various sources such as water, oil, coal, the sun, and others (Mohammed, 2021; Deora et al., 2022; Ali et al., 2021). This energy varies from a few volts to thousands or even millions of volts. One possible solution is to utilize alternative energy derived from readily available and underutilized materials. This environmentally friendly alternative energy can be renewed through the processing of organic waste such as vegetable and fruit scraps (D. Sintiya and Nurmasyitah, 2019; Rimantho et al., 2024; Saha et al., 2024).

Several types of fruit can be used to generate electrical energy, including oranges, mangoes, and apples. The pH of oranges is lower than that of mangoes, while the current level of oranges is higher than that of mangoes (D. Departement, F. Faculty, 2015). Thus, there is an inverse relationship between the current level and the acidity of oranges and mangoes, namely the more acidic (the lower the pH), the greater the current produced in the solution, and vice versa, the higher the pH will produce a smaller current in the solution (Hartini, 2013; Rokhim et al., 2024; Shibuya et al., 2024).

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The use of disposable batteries can cause environmental pollution due to the lack of facilities to process battery waste, so many end up in landfills (MH Baktiyar, A. Adiningrum, F. Septianingsih, and B. Poerwadi, 2015). One way to mitigate this problem is by creating biobatteries (M. Biobaterai and R. Lingkungan, 2021), (Khairiah and R. Destini, 2017). Biobatteries are devices that can produce electrical energy from materials derived from living organisms (Kırmızıtaş et al., 2024; Elhadad et al., 2022; Alrashidi et al., 2025).

Acidic solutions can conduct electricity and produce an electric current. Therefore, all sour fruits can produce an electric current (Sigalingging et al., 2022; Munthe et al., 2023; Sardewi et al., 2025). Based on this explanation, the citric acid contained in fruit can be used as an element in biobatteries. Lime and tangerine solutions have a low pH, so an electric current can be generated when copper and zinc plates are connected (Abdolsattari et al., 2022; Segundo et al., 2024; Beheiry et al., 2023). According to research conducted by Dian on oranges with a volume of 250 ml and Cu-Zn electrodes, a current of 0.5 mA was produced (J. Scienceet al, 2013). Mangoes, when combined with copper/Cu and zinc/Zn, can also produce electrical energy. In electrolyte solutions, electrons move through ions, which can be formed from acids, bases, or salts (H. Kamilah, T. Wardoyo, and S. Maftukhah, 2022; Ortega et al., 2022; Liang et al., 2023).

The development of biobatteries is crucial, as we cannot escape the use of batteries in our daily lives (Njema et al., 2024; Navarro & Esquivel, 2023; Mittal et al., 2021). Batteries function to convert the chemical energy present in active materials into electrical energy through electrochemical reduction and oxidation reactions, which occur on the electrode surface (A. Ristiono and M. Pd, 2010). The conductivity of a solution is influenced by the number of ions, ion movement, oxidation number, and temperature (Ringsby et al., 2021; Resta, 2021; Tian et al., 2023).

Citrus fruits and vegetables contain mineral acids such as hydrochloric acid and citric acid, which are strong electrolytes that completely dissociate into ions in aqueous solutions (Chaudhary et al., 2024; Burgess et al., 2024; Sharma et al., 2024). In addition to being acidic, citrus fruits and vegetables also have a high water content. Therefore, when two different metals are immersed in these vegetable solutions, a potential difference is created between the metal and the solution, creating an electrode potential and generating an electric current. Based on this, citrus fruits and vegetables can function as electrolytes that replace batteries, much like biobatteries (Sigalingging & Sitorus, 2024; Widyaningsih et al., 2024; Widyaningsih & Rahman, 2025).

Methods

In this study, a systematic literature review research methodology is used to investigate the viability of orange peel, fruit, and vegetable waste as bio-benign electrolytes of bio-batteries. The methodology will aim at ensuring that it has a universal coverage, and will generate a clear picture of the topic being examined.

Literature search was done in the existing scientific databases such as Scopus, ScienceDirect, Google Scholar and PubMed. Some of the keywords used by the search strategy include bio-battery, fruit peel electrolyte, vegetable waste electrolyte and green energy. The restrictions on the publication year were avoided on purpose to make the breadth and relevance as much as possible. Checking of the obtained records was performed in relation to the preset inclusion criteria, namely, the use of organic waste as an electrolyte in bio-batteries, that is, a fruit and vegetable peel, and quantitative indicators of electrochemical performance (e.g., voltage,

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current, conductivity, or pH). Articles that were not relevant enough or had no quantitative data were then filtered out.

After selecting articles, data extraction was conducted after that. The extracted data were stratified into the below categories: waste typology (e.g., orange peel, lime, tamarind), electrolyte preparation or extraction methodologies (e.g., crushing, filtration, aqueous blending), chemical characterisation (pH, conductivity, acid content- especially citric acid), bio-battery architecture (electrode type, surface area, inter-electrode spacing) and the performance indicators (open-circuit voltage, current, power output, and stability). It is through analytical synthesis of the data that had been compiled that the most common trends and gains, as well as limitations, were identified in relation to the use of organic waste as electrolytes in bio-batteries.

During the final step, the results obtained on the basis of the chosen studies were incorporated into a logical story report. The comparison of the findings highlighted the future benefits and the natural obstacles involved in the use of the organic waste as a sustainable electrolyte. The synthesis also tested the possibility of replacing hazardous chemicals in standard batteries by the equivalents produced by waste, and discussed the resulting environmental impact. These findings provide a deeper insight into the topic and outline the directions of the future research work.

Results and Discussion

There are several methods for obtaining electrolyte solutions that can replace electrolytes in bio-batteries by utilizing waste from citrus and vegetable peels, including:

Orange Peel (Citrus Sinensis) as a Material for Making Electrolytes in Bio-Batteries

Efforts to reduce the use of polluting chemicals require innovation to address this problem. One way is to replace the chemicals in batteries with orange peel waste. Orange peel contains citric acid (C_6H8O7) which can be used as an electrolyte solution for recharging batteries because citric acid can produce cations and anions which are conductive.

This research aims to create a new innovation so that the batteries used today do not only depend on synthetic chemicals, determine the pH value of orange peel, whether it is suitable for the production of electrolytes in batteries or not, find the maximum current and voltage values. Unused fruits are used as electrolytes in batteries, understand the operating principle of bio batteries using orange peel as a raw material for making electrolytes, utilize rich natural resources, and minimize the impact of environmental pollution due to components in batteries made from synthetic chemicals.

The research method was carried out by sorting the orange peel then crushing it, after adding H2O water.$_2$O, the resulting mixture is mixed thoroughly, then the water in the orange peel mixture is separated. The solution is then mixed with charcoal and dried until the mixed water is lower than 50%, to be ready for use as an electrolyte in the battery. The results show that orange peel has a pH of 3.8 and is acidic, so it can be used as an electrolyte in the battery. The electrolyte produced by orange peel has a potential difference of 0.81 Volts and a current of 0.049 mA with a load resistance of 4.7 KΩ. The battery capacity is 4 cm long, 2 cm wide and 9 cm high for a usable battery capacity of 4,752 mAh with a voltage of 0.8 Volts.

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Figure 1. pH Test Results

Lime Filtration with Added NaCl + Na-EDTA

The results of the lime filtration experiment in the electrolysis cell were carried out with two treatments, namely[12]: electrolysis using lime filtration and lime filtration with NaCl and Na-EDTA solutions obtained, after conducting experiments and observing the objects. obtained both types of electrolytes that can produce a potential difference but the value is not as large as the H2SO4 electrolyte. In addition, the refilling process is not as fast as the H2SO4 electrolyte, but in lime filtration electrolyte, NaCl Na-EDTA solution, the impedance quality and charging rate in unloaded and loaded conditions are almost the same as those in the H2SO4 electrolysis cell.

Figure 2. Lime juice filtering process

Identification of Orange Fruit Variations in Determining Electric Current Potential

The research method used in this study is an experimental method. The electrodes are in the form of plates measuring 4 cm x 2 cm. This research was conducted in four stages: collecting

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the fruit juice, testing different orange juices, testing the volume of juice used, testing the distance between electrodes, and measuring the pH of the orange juice using a pH meter.

Based on experiments conducted by testing the potential difference of several citrus varieties, electrode spacing differences, and volume differences, limes have the highest potential value among citrus plants. This proves the high acid content of limes; the more acidic the juice, the better its conductivity and the greater the electrical energy produced. Generally, if a conductive electrolyte solution has a high acid concentration, more ions will be produced, thus increasing the current and thus the conductivity of the electrolyte solution.

The results of testing various citrus varieties can be seen in Table 1. From the experiments conducted, it can be seen that lime juice has the highest potential value among other citrus cultivars. Indeed, the citric acid content (C_6H8O7) contained in limes in large quantities. Based on data analysis, it can be concluded that the acidity of citrus fruits affects the strength of the electric current. The more acidic the solution, the stronger the current, and vice versa, the higher the pH. The lower the pH, the lower the amperage.

Table 1. Electrical Voltage of Various Types of Oranges

Measurement	Electric Voltage (Volts)			
	Lime	Pomelo	Lime	Siamese Orange
1	1.96	1.34	1.56	0.86
2	1.95	1.21	1.48	0.85
3	1.99	1.3	1.45	0.81
4	1.9	1.26	1.45	0.8
x	7.8	5.11	5.94	3.32
$\bar{x}$	1.95	1.28	1.49	0.83

Electrical Analysis of Combination of Orange Peel and Tamarind for Bio-battery Application as an Alternative Energy

The use of disposable primary batteries can cause environmental pollution due to the lack of waste disposal facilities, which result in them being discarded as waste. One effort to reduce this pollution is the production of biobatteries. Biobatteries are devices that generate electrical energy from materials derived from living organisms. Fruit is one of the most promising materials for use in biobatteries. Orange peel and tamarind have high electrolyte content, making them suitable for use as electrolytes in batteries.

Several biobattery studies have been conducted, including those using waste from durian peel, coconut, banana, Terminalia cattapa, and orange and orange peel. This study aimed to determine the effect of a good current on various combinations of orange peel and tamarind to create biobatteries. The method used was to grind the orange peel and tamarind into a paste, mix them in various ways, and then insert them into used batteries.

The results of the voltage test for the different ratios of orange peel and tamarind showed that the highest voltage was obtained with a variable percentage of orange peel of 25%, namely 1.7 volts, while the lowest was obtained with a variable percentage of orange peel of 100%, namely 1.43 volts. Changes in orange peel and variations in acid affect the voltage because ions accumulate at the cathode so that a number of charges flow from the anode to the cathode. The more ions that collect, the more voltage is produced.

Table 2 shows the variation in the percentage of orange peel to acid based on the results of electrical current observations. The results showed that the highest electric current value was

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found in the orange peel variation with a percentage of 25%, namely in the orange peel variation of 1.33 mA, while the lowest value was found in the orange peel variation with a percentage of 0%, namely 0.63. A variation of 0% in orange peel means an acid concentration of 100%, which indicates a very concentrated acid variation in the paste. Due to this density, the ion concentration is very dense and dense, making it difficult for the existing ions to absorb, move and produce a small electric current. Meanwhile, in the 25% variation, the ions move widely, making it easier to move because of the reduced density of the orange peel. This current value is influenced by the voltage and resistance of the battery.

Table 2. Electric Current From The Variation In The Percentage Of Orange Peel Against Tamarind

No	**Percentage of orange peel against tamarind (%)**	**Electric Current (mA)**
1	0	0.62
2	25	1.33
3	50	0.92
4	75	0.95
5	100	1.20

Test results showed that the ratio of orange peel to tamarind affected the voltage and current. The best biobattery was when the percentage of orange peel to tamarind was 25%.

Fruit and Vegetables as a Potential Source of Alternative Electrical Energy

Of the total organic waste in the city, approximately 60% is vegetables and 40% is leaves, fruit peels, and food scraps. Fruits contain substances such as ascorbic acid, citric acid, and NADH (Nicotinamide Adenosine Dinucleotide Hydrogen), which energize cells under certain conditions. These chemicals act as electrolytes. Due to the electrical properties of fruit and vegetable waste, which contain many electrolytes, it can be used as a renewable alternative energy source in the form of a biobattery to replace conventional batteries. The development of vegetable and vegetable waste as a biobattery will make a significant contribution to the scientific world in particular and society in general. Data collection from previous research was carried out and then analyzed based on existing parameters. There are various parameters related to the electrical properties of fruits and vegetables. Different fruits and vegetables produce different currents and voltages. Fruits and vegetables have different pH levels (acidity), where pH is inversely proportional to current and voltage. In addition, the type of electrode used also affects the electrical characteristics. The distance between electrodes is inversely proportional to the amperage and potential difference in vegetable waste. Installing bio-batteries in series and parallel can increase the current and voltage.

Fruits and vegetables have various electrical properties. Research conducted by Muhlisin et al (2015) compared banana peels and durian peels as battery pastes. The resulting voltage indicates the electrical properties of each fruit. The maximum voltage value obtained from peeled banana paste was greater than that of durian peel, namely 1.12 volts, while banana peels and durian peels were 0.99 volts. And Ambon bananas were the best bananas used in this experiment as a substitute for battery paste. The electrical properties of various types of fruits and vegetables can be seen in tables 3, 4, 5, and 6.

Table 3. Results of Voltage Measurement Banana Peel Ambon

No	**Weight (gr)**	**Electrolyte Mass (gr)**	**Voltage (V)**	**Current (mA)**
1	34	19	0.62	0.12

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2	34	19	0.68	1
3	34	20	0.89	2.7
4	34	20	0.85	2.85
5	34	21	0.95	4
6	34	22	1	5
7	34	22	1	5.5
8	34	22	1.09	7.8
9	34	22	1.09	9.5
10	34	25	1.2	10

Table 4. Results of Voltage Measurement Janten Banana Peel

No	Weight (gr)	Electrolyte Mass (gr)	Voltage (V)	Current (mA)
1	34	17	0.45	0.15
2	34	18	0.51	0.17
3	34	19	0.6	0.67
4	34	20	0.62	0.82
5	34	21	0.75	0.87
6	34	22	0.77	2.1
7	34	22	0.9	1.9
8	34	22	1.96	3
9	34	23	1	4
10	34	25	1.07	9

Table 5. Results of Voltage Measurement Banana Peel Mali

No	Weight (gr)	Electrolyte Mass (gr)	Voltage (V)	Current (mA)
1	34	18	0.52	0.5
2	34	19	0.55	0.55
3	34	20	0.62	0.65
4	34	20	0.62	0.98
5	34	22	0.69	1.02
6	34	23	0.72	1.5
7	34	24	0.74	1.8
8	34	25	0.8	2.9
9	34	25	0.98	4.3
10	34	25	1.05	6.5

The Effect of Electrode Materials on the Electrical Properties of Oranges and Tomatoes as an Alternative Energy Solution

Electrolyte solutions are solutions composed of acid, base, and salt ions. Acids consist of strong acids, which produce many ions, and weak acids, which produce few ions. The more acidic the solution, the lower the pH value, and the weaker the solution, the higher the pH value.

Strong and weak acidic fruits can be identified by their pH, such as limes and tomatoes. Both fruits have a pH between 4-5, meaning an acidic acid is a weak acid. Electrons continuously move from the anode to the cathode, and this reaction repeats to produce electricity. Tomatoes and limes can produce ions, which can produce electricity.

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The data obtained from this study were measured five times to ensure accuracy. Differences in measured voltage and current values are caused by varying acidity levels. The voltage and electric current in this study can be explained based on the working principle of a galvanic cell. Two different electrodes are placed in an electrolyte solution, which generates electricity through a chemical reaction. The chemical reaction that occurs is a redox reaction. The anode (Fe, Mg) will undergo an oxidation process, while the cathode (Cu) will undergo a reduction process.

Table 6. Results of Voltage Measurement Durian Peel

No	Weight (gr)	Electrolyte Mass (gr)	Voltage (V)	Current (mA)
1	34	18	0.45	0.23
2	34	21	0.55	0.24
3	34	22	0.56	0.37
4	34	23	0.63	0.4
5	34	23	0.8	0.72
6	34	23	0.82	1.5
7	34	24	0.88	1.7
8	34	24	0.94	2.84
9	34	25	0.95	7
10	34	25	0.99	10

Table 7. Experiment of Lime with Copper (Cu) and Iron (Fe)

Test	Voltage (V)	Current Strength (mA)
1 Orange	0.98	0.18
2 Oranges	1.92	0.17
3 Oranges	2.40	0.14
4 Oranges	3.24	0.12
5 Oranges	4.11	0.10
6 Oranges	4.92	0.09
7 Oranges	5.67	0.07

Table 8. Experiment of Lime with Copper (Cu) and Magnesium

Test	Voltage (V)	Current Strength (mA)
1 Orange	1.67	0.42
2 Oranges	3.32	0.34
3 Oranges	4.33	0.30
4 Oranges	5.78	0.27
5 Oranges	6.37	0.24
6 Oranges	7.25	0.19
7 Oranges	8.62	0.15

Table 9. Experiment of Tomatoes with Copper (Cu) and Iron (Fe)

Test	Voltage (V)	Current Strength (mA)
1 Tomato	0.77	0.32
2 Tomatoes	1.70	0.30
3 Tomatoes	2.74	0.29
4 Tomatoes	4.48	0.28
5 Tomatoes	5.09	0.26

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6 Tomatoes	5.82	0.22
7 Tomatoes	6.59	0.21

Table 10. Experiment of Tomatoes with Copper (Cu) and Magnesium

Test	Voltage (V)	Current Strength (mA)
1 Tomato	1.69	0.76
2 Tomatoes	3.37	0.67
3 Tomatoes	4.86	0.53
4 Tomatoes	5.97	0.49
5 Tomatoes	6.78	0.41
6 Tomatoes	7.64	0.34
7 Tomatoes	8.91	0.29

Current measurements on limes and tomatoes using copper and iron electrodes showed a value of 0.18 mA for one lime and 0.07 mA for seven limes. Meanwhile, one tomato yielded a value of 0.32 mA, and seven tomatoes yielded a value of 0.21 mA. A measurable decrease in current was observed with increasing number of limes.

When measuring voltage with iron and copper, one lime produced 0.98 volts, while seven limes produced 5.67 volts. On the other hand, one tomato produced 0.77 volts, and seven tomatoes produced 6.59 volts. The measured voltage increased as the number of fruits increased.

In the copper-magnesium current test, one lime produced 0.42 mA, and seven limes produced 0.15 mA. One tomato produced 0.76 mA, while seven tomatoes produced 0.29 mA. The measured current decreased with increasing number of fruits.

Voltage measurements using copper-magnesium showed 1.67 volts for one lime and 8.62 volts for seven limes. Meanwhile, one tomato produced 1.69 volts, and seven tomatoes produced 8.91 volts. The measured voltage also increased with increasing fruit count.

Based on the analysis of the tests listed in tables 7, 8, 9, and 10, the Cu-Fe electrode produces lower current and voltage compared to the use of the Cu-Mg electrode in the electrical experiments on tomatoes and limes.

Conclusion

Based on the research that has been done, electrolytes from citrus and vegetable peel waste can be used as a new alternative to replace electrolytes in batteries that currently still use a lot of chemicals, but electrolytes from citrus and vegetable peel waste still need further development before they can be used. Electrolytes obtained from the extraction of citrus and vegetable peel waste have acidic properties so they can be used as electrolytes in making batteries, in addition citrus and vegetable peels also contain citric acid C6H8O7 which belongs to the acid group. Batteries made from citrus and vegetable peel waste as electrolytes can produce current and voltage.

Fruits contain substances such as ascorbic acid, citric acid, and NADH (Nicotinamide Adenosine Dinucleotide Hydrogen), which provide energy to cells under certain conditions. These chemicals act as electrolytes. Due to its electrical properties, which contain many electrolytes from fruit and vegetable waste, it can be used as a renewable alternative energy source in the form of a bio-battery to replace conventional batteries. The development of vegetable and fruit waste as a bio-battery will make a significant contribution to the scientific world in particular and society in general.

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